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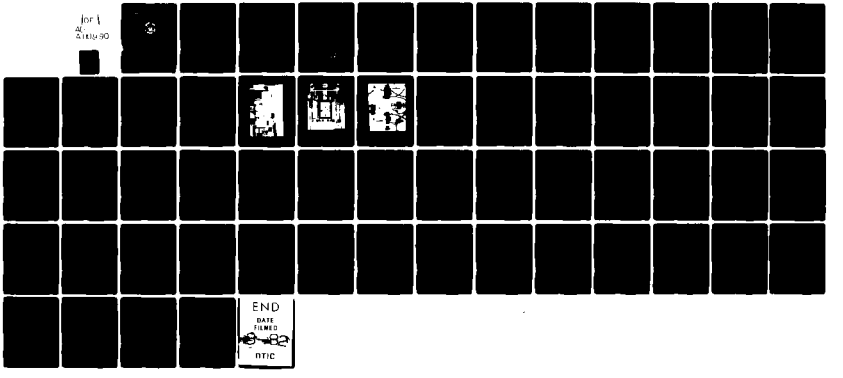

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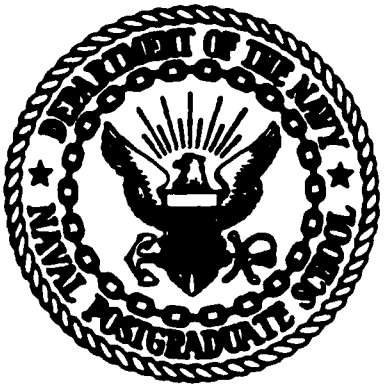

THESIS

DESIGN AND VALIDATION OF AN APPARATUS FOR HIGH TEMPERATURE FATIGUE TESTING IN AN INERT ENVIRONMENT

by

William Aaron Hastie Jr.

September 1981

Thesis Advisor: K. D. Challenger

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by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

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September 1981

Author _____

Approved by: _____
Thesis Advisor

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Second Reader

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Dean of Science and Engineering

ABSTRACT

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I. INTRODUCTION

Annealled 2¼ Cr - 1 Mo steel is a ferritic low-alloy steel that has been used extensively for elevated-temperature applications in the power generation industry. Recently, the alloy has been selected as the structural material for steam generators in the Liquid Metal Fast Breeder Reactor (LMFBR). Because the ASME Pressure Vessel Code requires accurate predictions be made for high temperature fatigue life of materials used in nuclear applications, a series of creep and high temperature fatigue tests have been run on this alloy.

This thesis research is concerned with the design and validation of a system which permits testing of this alloy at high temperatures under creep, fatigue, and creep-fatigue loading conditions in a controlled gaseous environment.

The balance of this paper will present the background of the effects of oxidation on elevated temperature fatigue, a discussion of the apparatus and procedures, a discussion of the results obtained, and conclusions and recommendations. Appendix A provides a detailed checklist for performing the elevated temperature fatigue tests, that was developed during the course of this research.

II. BACKGROUND

Components in power generating plants must withstand local cyclic strains beyond yield. For example, high temperature components are subjected to considerable temperature change and resulting thermal gradients each time the plant is started up, shutdown or experiences load changes. These thermal changes subject the components to thermal stress-strain cycles which may involve plastic flow. In any particular cycle, a component may be caused to locally yield in both tension and compression and the material may be held for a considerable time in a strained state at elevated temperature resulting in creep deformation interspersed with fatigue loading.

Numerous investigations have been conducted on high temperature fatigue, creep and creep fatigue interaction. During the last few years, it has become a highly debated question as to what extent the environment affects cyclic life at elevated temperature as compared to the role of creep damage. It is well established that both creep and oxidation are time dependent processes and it is indeed a difficult problem to distinguish the effect of creep from that of oxidation.

Several studies have been carried out in which the testing was conducted in vacuum and inert gases, however, no atmosphere can be considered totally inert. Inert gases will not readily absorb on or dissolve in metals [Ref. 1], however, impurities in the inert gases can dissolve and absorb. Maintaining total impurity levels below about 0.2 ppm is very difficult. Unfortunately, accurate reporting of impurity level

present during testing does not often accompany results of tests conducted in vacuum and inert gases [Ref. 2].

"Two important parameters controlling rate of oxidation are oxygen availability and solid-state diffusion rates. The effect of the former is summarized by:

$$\text{Oxidation rate} \propto (P_{O_2})^{1/n}$$

where n is between 2 and 3 depending on the details of the reaction [Ref. 3]. The second arises when the reaction, occurring at the oxide/metal interface, is controlled by diffusion of oxygen through the oxide, producing a stress at the interface. Alternately when the reaction occurs at the oxide/gas interface it requires an outward flow of metal atoms causing vacancy accumulation near or below the oxide/metal interface" [Ref. 2]. Thus, the mechanism of oxidation for a given alloy controls the influence of environment.

Alloying elements may also be lost at the surface through evaporation [Ref. 4]. It has been argued [Ref. 5] that the oxide free surface of specimens tested in argon allowed selective evaporation of alloying elements from steels and nickel based alloys, which led to a reduction of creep and fatigue resistance. Additionally, if evaporative loss is important, it will be less in an inert gas than in a vacuum because of the shorted mean-free path of the evaporating species [Refs. 2,6]. This suggests that the inherent fatigue or creep strength is best measured in an inert environment rather than a high vacuum.

Ericsson in his excellent review [Ref. 7] provided the following information. The crack growth rate in air is generally an order of

magnitude faster than in a vacuum at elevated temperature. This effect increases with increasing temperature. The tendency for lower frequency and air environment to promote intercrystalline fracture is evident. Skelton [Ref. 8] found that the fatigue life in vacuum as well as in air decreased with decreasing frequency. Similar findings have been reported by Solomon and Coffin [Refs. 9,10], suggesting that a synergistic interaction between creep and fatigue may exist along with an environmental effect.

Oxidation has been observed to effect fatigue crack initiation and propagation. Coffin [Ref. 11] reports that in alloy A-286 tested in air at 593 °C fatigue cracks nucleated from "active sites" which were intensely oxided. In addition to the effects on crack initiation, grain boundary oxidation ahead of a crack has been shown to weaken the grain boundary and promote intergranular grain boundary crack propagation [Refs. 7, 11, 12, 13].

The use of $2\frac{1}{4}$ Cr - 1 Mo steel in power generating systems results in its exposure to the complex creep fatigue loading in varying environments; e.g.: liquid sodium, air, steam and water. The most recent analysis of the creep-fatigue environment interaction phenomena in this alloy attributes the major reduction in elevated temperature fatigue life to oxidation rather than creep damage [Ref. 14]. Specifically, the mechanism was proposed to involve the formation and subsequent cracking of an oxide that assisted the initiation of a fatigue crack. Testing in impure helium has been reported to improve the high-cycle fatigue life [Ref. 15] and reduce the fatigue crack growth rate for this alloy [Ref. 16], indicating that oxidation influences both fatigue-crack initiation and growth for this alloy.

Current ASME design methods for analyzing the creep fatigue life ignore any environmental effect and attribute all reductions in fatigue life to an interaction between creep and fatigue damage. In view of the preceeding discussions, this is a very dangerous philosophy. Extrapolation of laboratory test data to actual service conditions involves extrapolations of several orders of magnitude. If the method of extrapolation is based on an incorrect physical mechanism, this extrapolation will be seriously in error.

A separation of the effects of creep and environmental damage on fatigue is paramount in the development of improved elevated temperature design methods. This requires the design and construction of complex and expensive elevated temperature fatigue testing equipment.

III. EXPERIMENTAL

A. APPARATUS

The purpose of this research was to design and set up an apparatus to study the interactions among fatigue, creep and environment for 2¼ Cr - 1 Mo steel. The apparatus consists of:

(1) MTS Closed-loop Electrohydraulic Testing System

a) MTS Model 312.41 Load Frame
b) MTS Model 661.21A-03 Load Cell
c) MTS Model 410.31 Function Generator
d) MTS Model 417.01 Counter Panel
e) MTS Model 442.11 Controller with Modules
f) MTS Model 506.20 Hydraulic Power Supply
g) Tektronixs Oscilloscope
h) Hewlett-Packard 7044 A X-Y Recorder

(2) Heater

a) Cycle-Dyne Model A-30 Induction Heater
b) MTS Model 632.50B High Temperature Extensometer
c) MTS Model 924.35 Temperature Control Panel
d) Newport Model 268 Digital Pyrometer
e) User designed Induction Coil

(3) MTS Model 651.1XA Environmental Chamber (Modified)

a) Ellison Manometer
b) Edwards High Vacuum Pump
c) Linde Helium Gas Cylinder

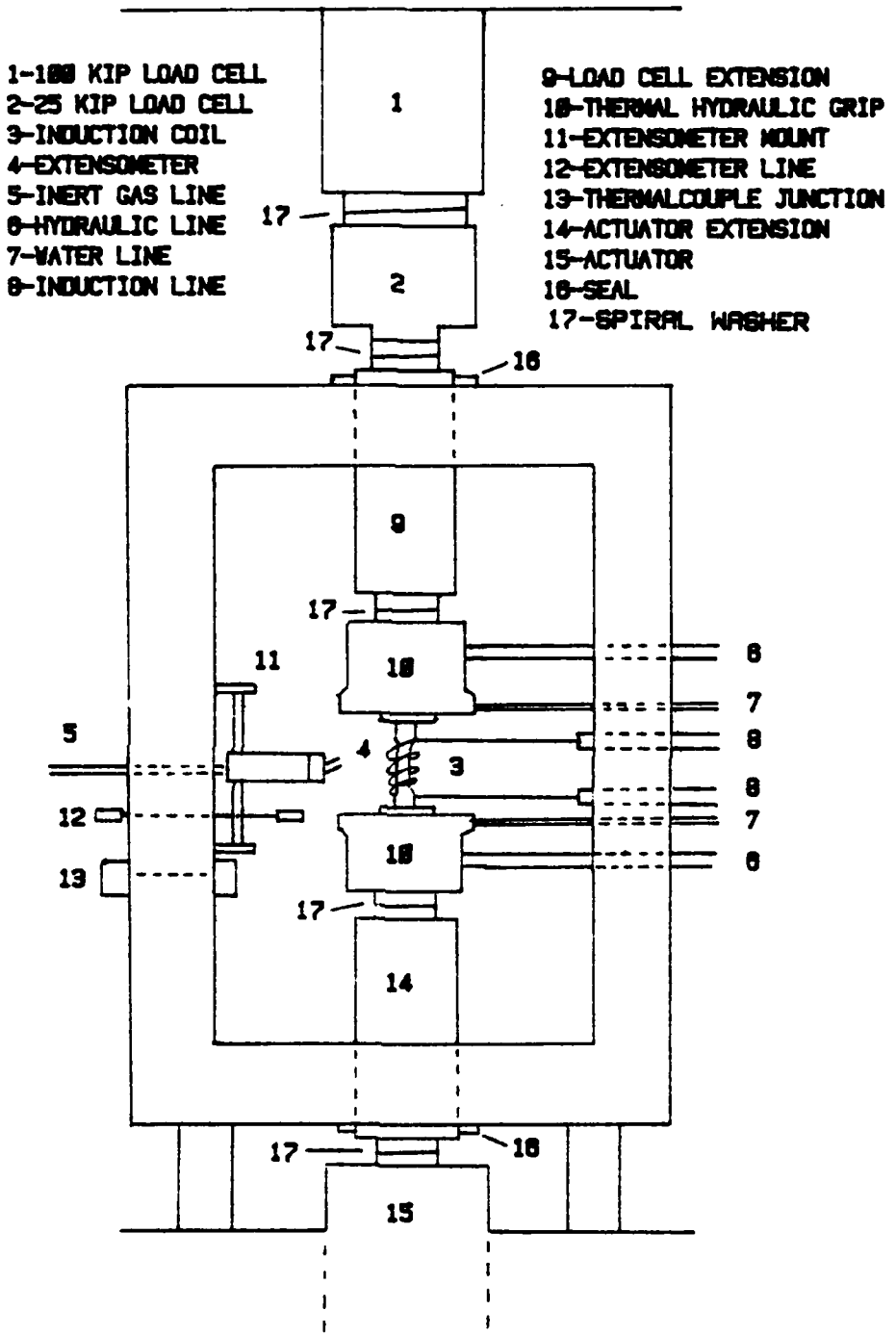

Figure 1. Schematic frontal view of Environmental Chamber (modified)

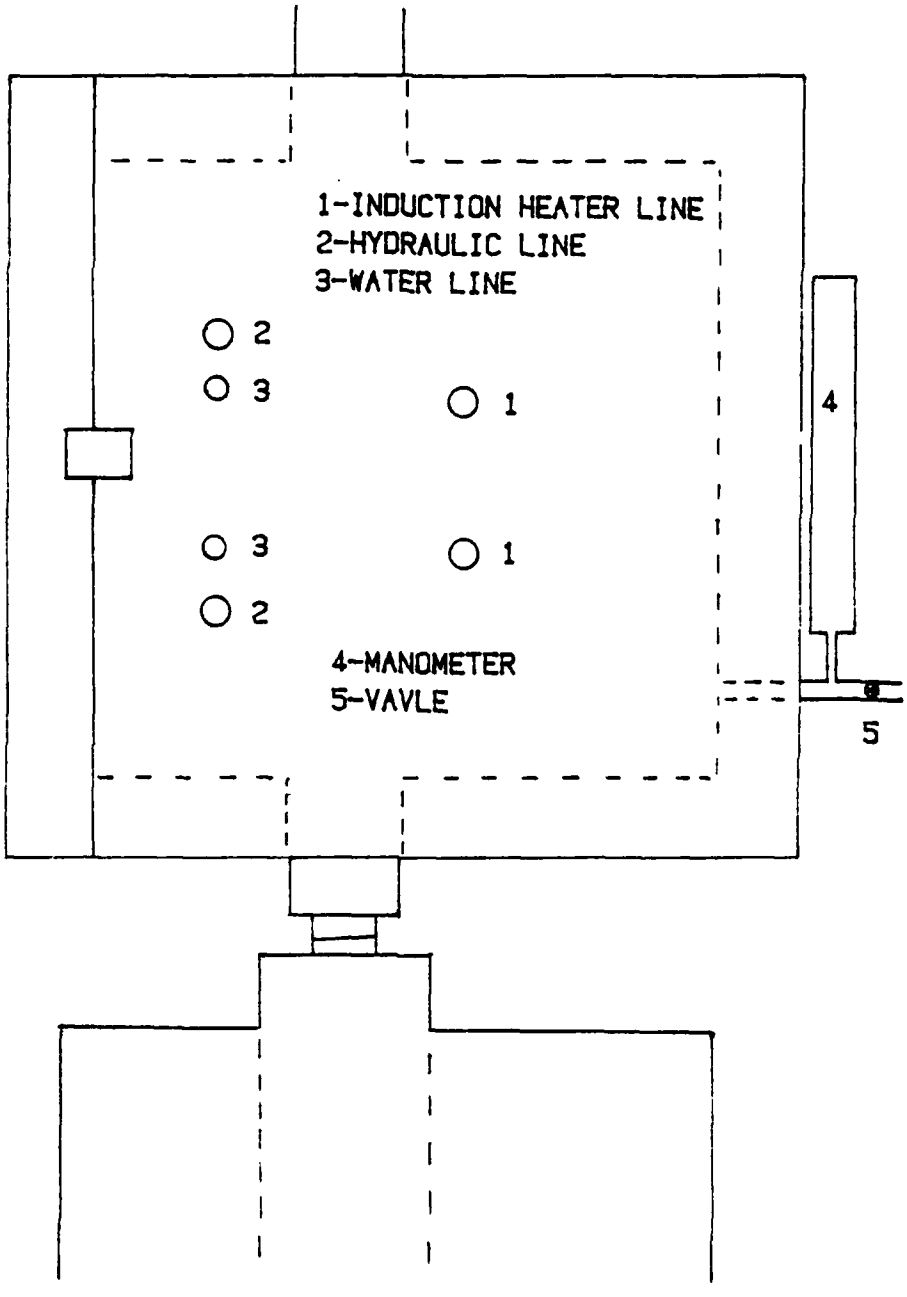

Figure 2. Schematic heater-side view of Environmental Chamber (modified)

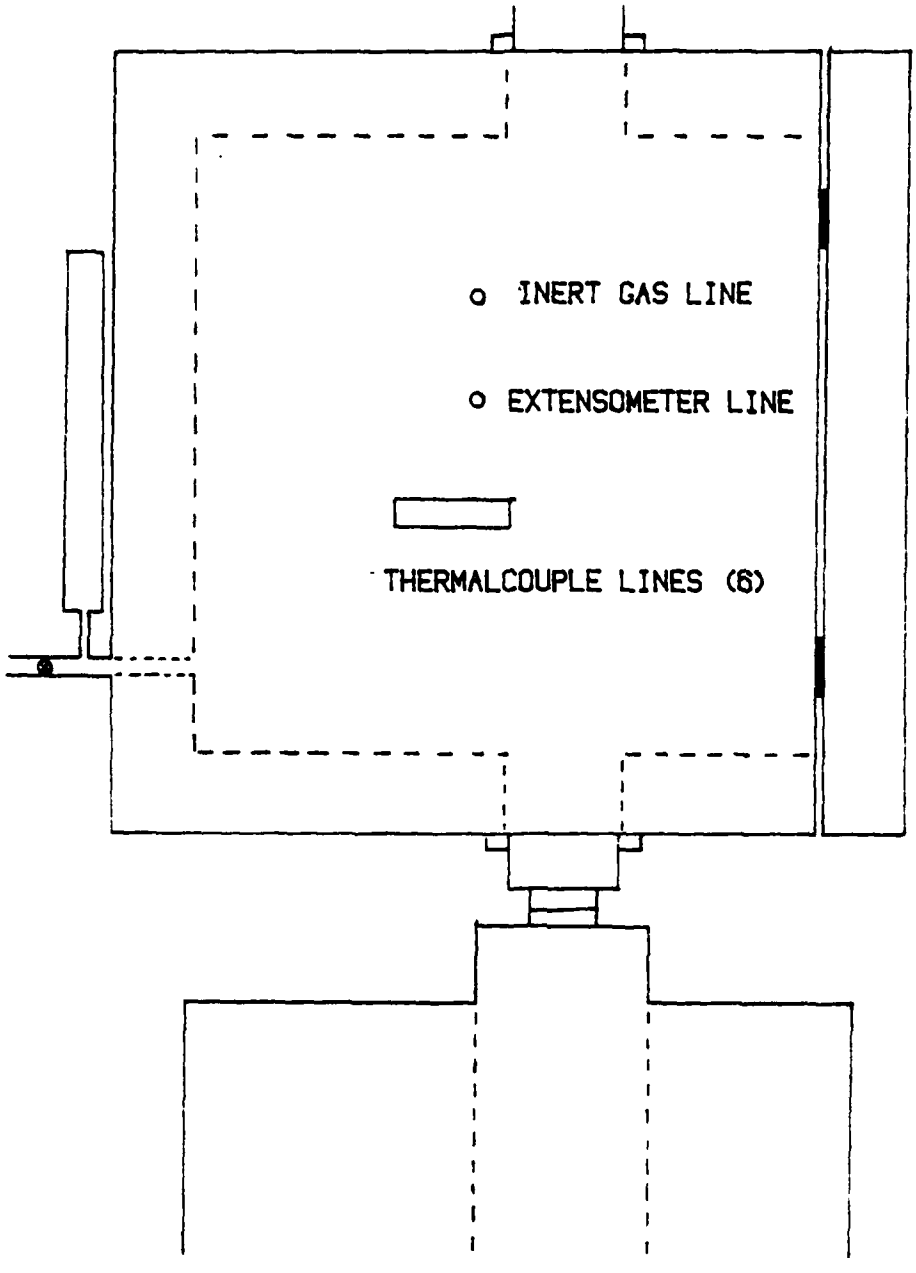

Figure 3. Schematic console-side view of Environmental Chamber (modified)

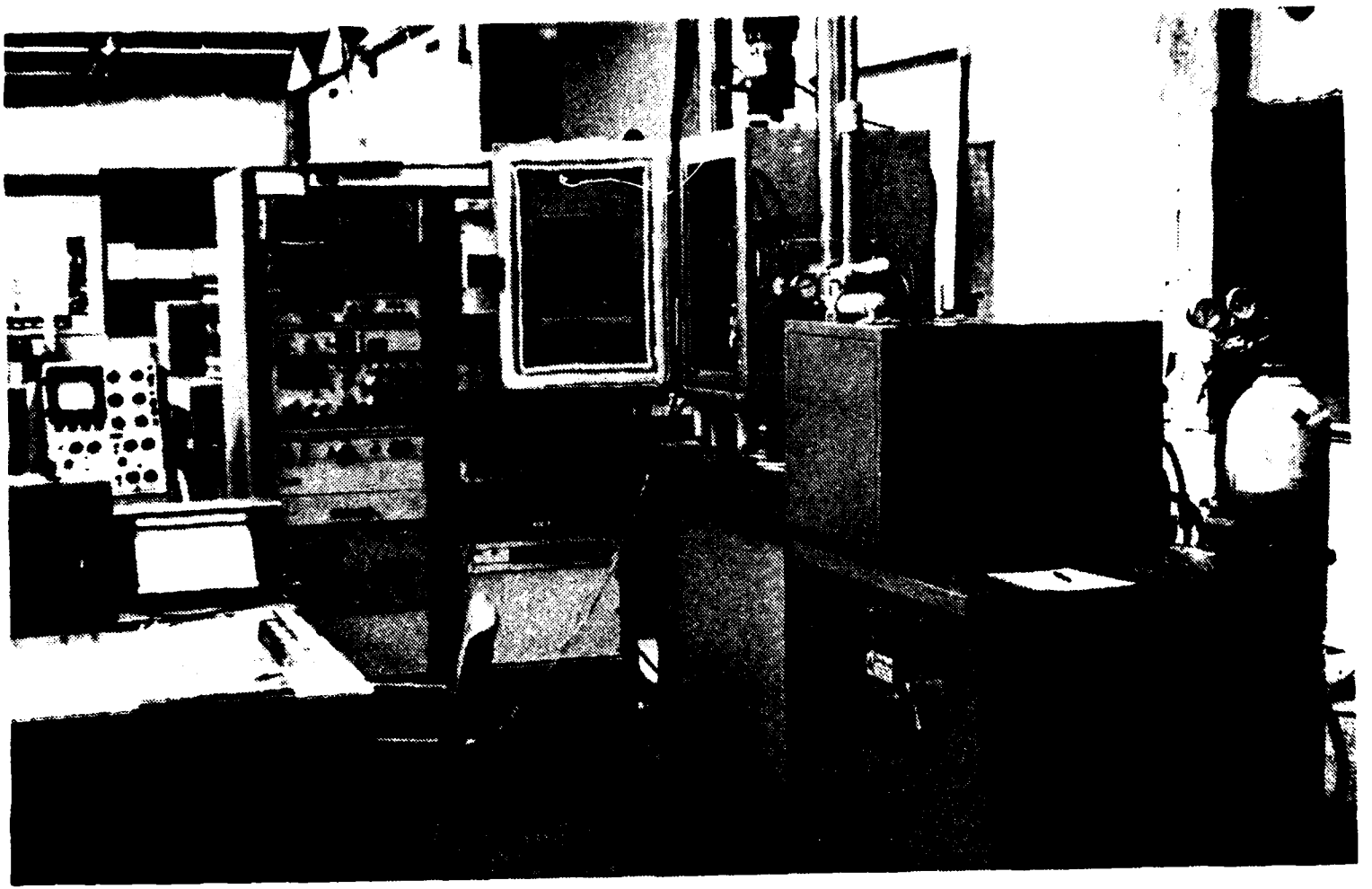

Figure 4. High Temperature Fatigue Testing Apparatus

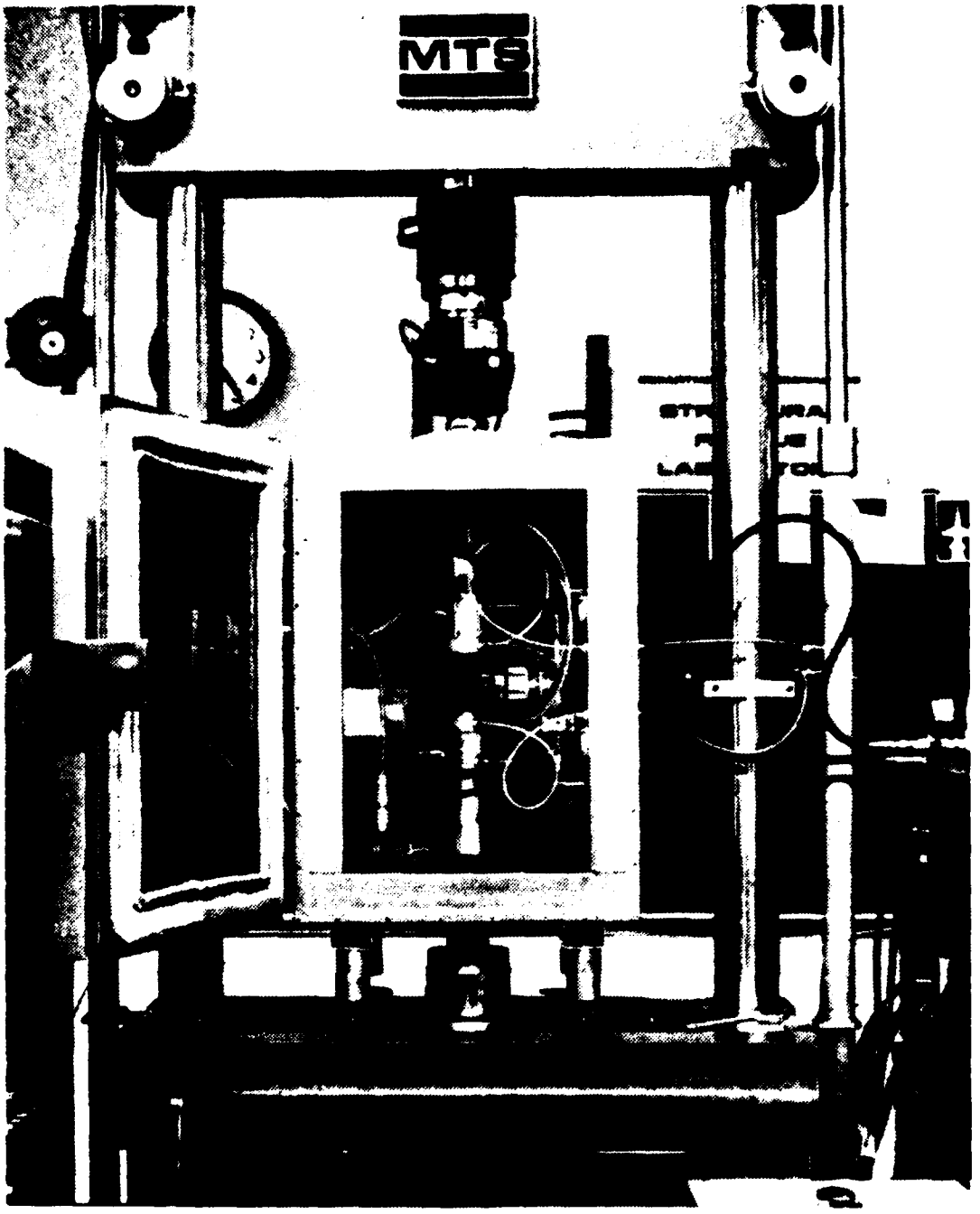

Figure 5. Photograph Environmental Chamber with Load Frame

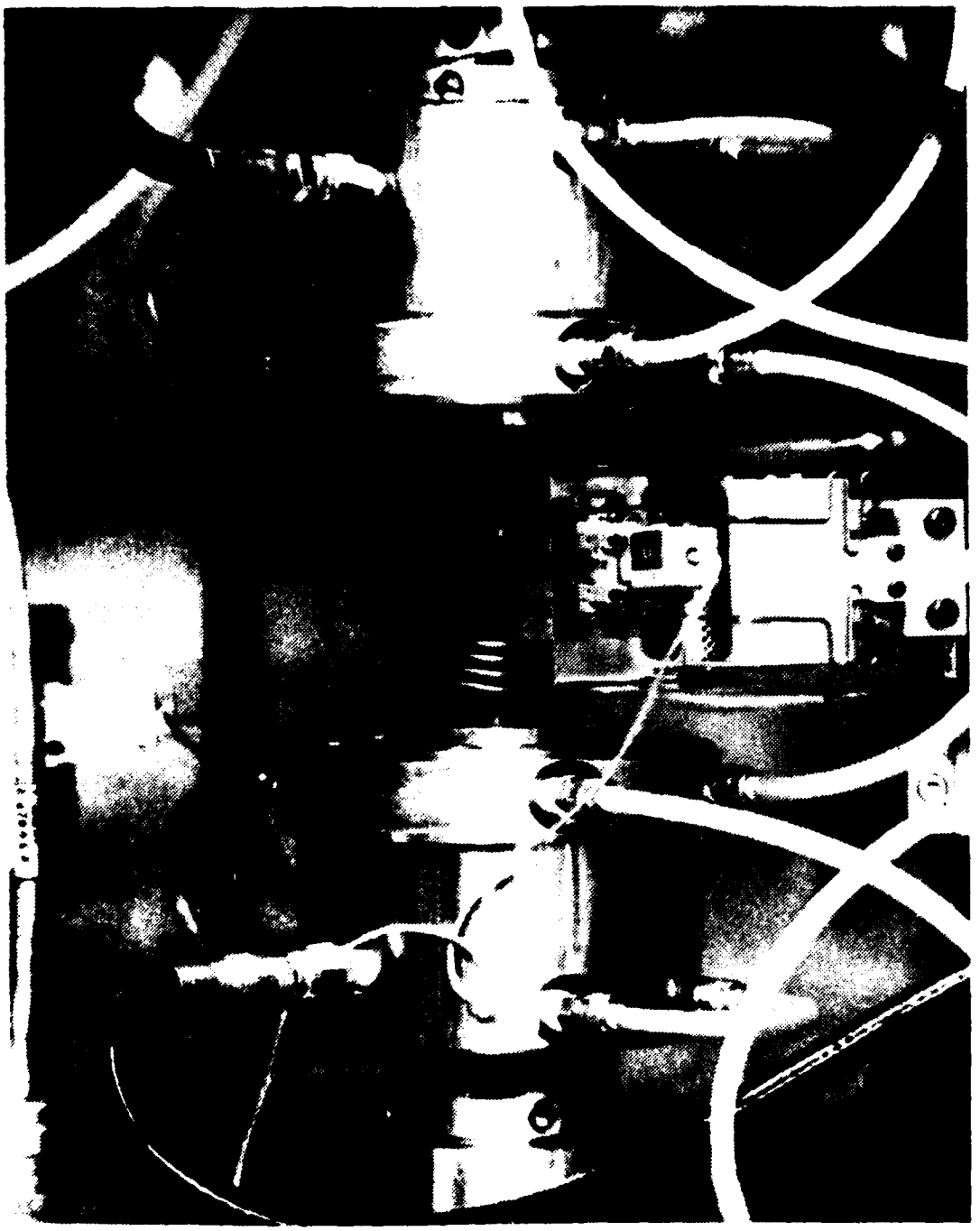

Figure 6. Close-up of Testing Apparatus

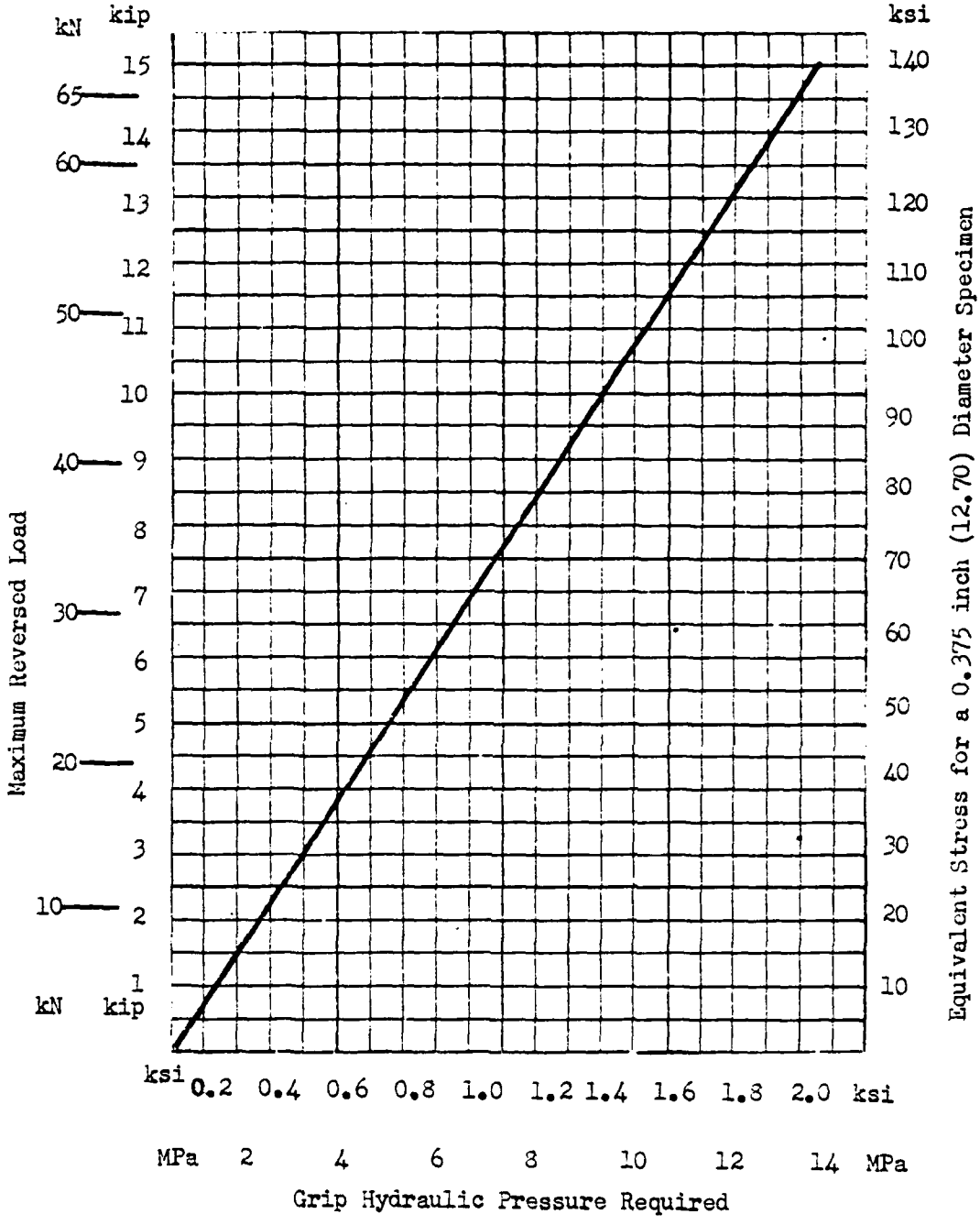

Figure 7. Maximum Totally Reversed Load Vs.
Grip Hydraulic Pressure

To obtain the integrated system described, it was necessary to extensively modify the Environmental Chamber. To accomplish this required the introduction of several ports for entry of hydraulic, water, inert gas, thermocouple, extensometer and induction heater lines. Stainless steel extensions were machined for the load cell and actuator. Closure and foam rubber seals were used on the upper and lower inlets and on the door, respectively. A manometer was attached to measure overpressure and a valve mechanism was installed for sampling and flushing. Finally, a mount was constructed for the extensometer.

To understand the operation of the entire system, it is necessary to detail the operation of several of the individual components. The hydraulic system used to pre-load the specimens (Item 6 Figure 1) and the spiral washers (Item 17 Figure 1) are required to prevent backlash in the system as the loading reverses from compression to tension and vice versa. The hydraulic preload is applied to the specimen buttonhead by a piston in each grip. The pressure which is to be applied by the hydraulic pump can be determined from Figure 7.

To prevent backlash in the remainder of the load train, spiral washers are positioned between each component. By placing a load on the system greater than the maxium load anticipated, and tightening the spiral washers, backlash is prevented.

The water-cooled grips (Item 10 Figure 1) also provide thermal protection for the actuator and load cells. Tap water is circulated through the grips and heat is removed from the grips allowing a maximum grip temperature of slightly greater than room temperature.

The gas-cooled extensometer (Item 4 Figure 1) provides direct axial strain measurement of the gage length. The use of quartz extension rods minimizes thermal expansion error and conduction losses from the specimen. The knife edge extension rods allow for use of uniform gage length specimens. The relative movement of the quartz rods is transmitted to a strain gage bridge to produce a strain reading. The extensometer is gas cooled due to the temperature-sensitive nature of the strain gages.

The induction coil (Item 3 Figure 1) and heater provide a very convenient means of achieving high temperatures (1000 ^{o}C). Furnace and other types of heating systems restrict the use of gas-cooled extensometers and entail other difficulties associated with heat removal. The user designed induction coil provides a uniform ($\pm 2^{o}$C) temperature profile on the specimen's gage length. The specimen geometry (Figure 8) and the fact that the thermal grips act as heat sinks, require the input of energy from the induction coil be concentrated outside the uniform gage length. It is necessary to position the spot-welded thermocouples outside the uniform gage length to prevent crack initiation at the site of the spot-weld. It is, therefore, necessary to determine the temperature profile with five thermocouples when designing and testing a coil. Three of the thermocouples are placed on uniform gage length and one each is placed on the blending fillets outside the gage length. Temperature readings are recorded and the coil modified to insure a uniform temperature. As a matter of course, both temperatures from the thermocouples outside the gage length are monitored during an actual test. One of these temperatures is a feedback to the temperature

controller and the other is recorded. Additionally, the second temperature is used as a crosscheck against the data recorded during induction coil design.

The specimen geometry in this study is shown in Figure 8. It was designed to ASTM E466 standards with the exception that the fillet radius blending the gage length with the 0.5 inch diameter of the specimen, is less than eight times the gage diameter. Previous experience has shown this to be larger than necessary to prevent crack initiation in the fillet.

B. PROCEDURE

Specimens used in this project were taken from a one-inch diameter rod of 2¼ Cr - 1 Mo steel obtained from Oak Ridge National Laboratory (ORNL), heat number 56447. Chemical analysis of representative material appears in Table I.

Table I

CHEMICAL COMPOSITION OF 2¼ Cr - 1 Mo STEEL HEAT NUMBER 56447

Content, wt%

C	Mn	Si	Cr	Mo	Ni	S	P
0.098	0.53	0.22	2.20	1.03	0.24	0.005	0.059

The melting practice used to produce the material was vacuum-arc remelt (VAR). The 6.25 inch sections of the rod were isothermally annealed as follows:

Austenitize at 927 ±14 ° C for one hour, cool to 704 ±14°C at a maximum cooling rate of 83°C/hour, hold at 704 ±14°C for two hours,

NOTES: 1. REMOVE ALL BURRS AND SHARP EDGES.
2. SURFACE ROUGHNESS $\sqrt{}$ UNLESS OTHERWISE SPECIFIED.
3. SPECIMEN TO BE IDENTIFIED AT ALL TIMES DURING FABRICATION WITH MATERIAL HEAT NO. PLATE NO. HEAT TREATMENT AND SPECIMEN NO. BY DIE MARKING OR MASKING TAPE AND LABELED ENVELOPES.
4. MARK WITH APPLICABLE SPECIMEN NUMBER ON BOTH ENDS (SAME NUMBER AS BLOCK) ENGRAVE,DO NOT STAMP. VIBRATING TYPE ENGRAVING TOOL IS PERMISSIBLE.
5. FINAL MACHINING OF THE REDUCED SECTION AREA OF THE SPECIMEN SHALL BE AS FOLLOWS:
   A. ROUGH MACHINING SHALL LEAVE 0.010 in. STOCK ON THE RADIUS OVER THE FINAL DIMENSION.
   B. USING A GRINDING WHEEL WITH ITS SHAFT AT 90° TO THE SPECIMEN LONGITUDINAL AXIS GRIND WET.
   C. REMOVE 0.0002 in. STOCK MATERIAL EACH PASS WHILE ROTATING THE SPECIMEN AT 325 rpm ABOUT ITS LONGITUDINAL AXIS , SIMULTANEOUSLY TRANSLATING THE SPECIMEN BACK AND FORTH UNDER THE GRINDING WHEEL, PARALLEL TO THE GRINDING WHEEL SHAFT AXIS.
   D. BUFF TO 8-11 MICROINCH FINISH BY POLISHING IN A MANNER PARALLEL TO THE SPECIMEN LONGITUDINAL AXIS.
   E. POLISH REDUCED AREA LONGITUDINALLY TO REMOVE ALL CIRCUMFERENTIAL WORK MARKS VISIBLE AT APPROXIMATELY 20X MAGNIFICATION UNDER A LIGHT MICROSCOPE.
6. ALL DIMENSIONS IN INCHES.
7. TOLERANCES: .xxx=0.005, .xx=0.030 UNLESS OTHERWISE SPECIFIED.

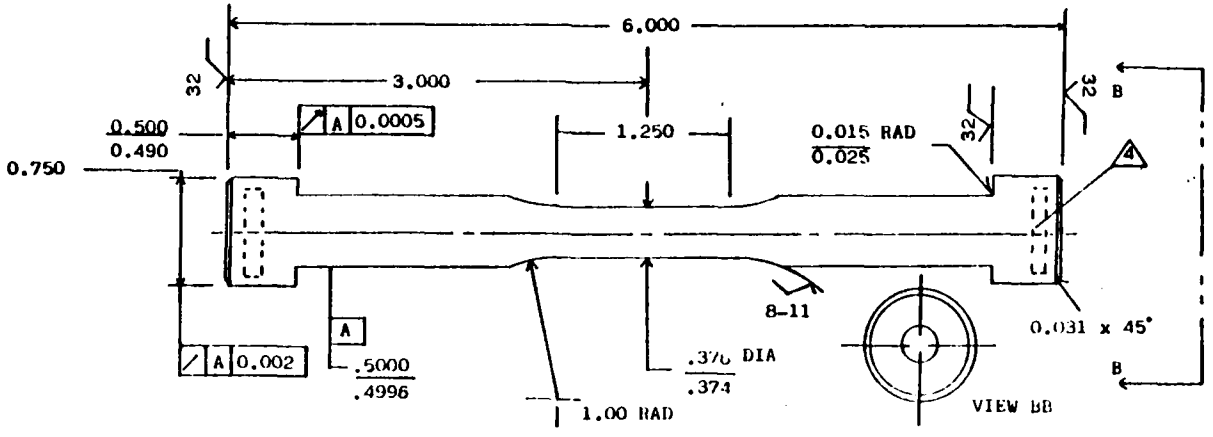

Figure 8. Specimen geometry and maching procedure

and cool to room temperature at a rate not to exceed 6°C/minute.

Uniform gage specimens with a .375 inch diameter were machined and polished to remove all circumferential machining marks. Figure 8 is a detailed drawing of specimen geometry and machining procedure.

Fully reversed axial push-pull testing was accomplished in a closed-loop electrohydraulic fatigue test machine under strain control. All tests were conducted with a strain rate of $4 \times 10^{-3} s^{-1}$. Heating of the specimen was obtained by induction with thermocouples spot welded on the blending fillets of the specimen outside the gage length. Tests were conducted at 482 and 538°C with a maximum temperature variation of ±2°C on the uniform gage length.

An inert environment of helium gas was used in four of the tests. In those tests, the chamber was flushed with forty cubic feet of helium and a positive pressure of 5 inches of water (.18 psig) was maintained in the chamber. The amount of oxygen in the chamber was monitored by sampling the gas in the chamber and analyzing the contents with the use of a gas chromatograph. Appendix B contains sample calculations based on gas chromatograph output.

Prior to testing, specimens were polished along the longitudinal axis and cleaned with acetone and then alcohol. After CONSOLE POWER is applied, the MTS Closed-loop Electrohydraulic Testing System is programmed. This programming includes selection of the operating ranges for each control variable, adjustment of desired function and failsafe and error detect adjustments. The specimen is then installed with the system in load control and the extensometer is mounted.

If an inert environment is to be utilized, the environmental chamber is flushed with the appropriate gas and a positive pressure is maintained before the induction heater is started and temperature is monitored. The specimen is heated to temperature under load control and zero load is maintained. This allows the specimen to expand without constraint. After the specimen reaches testing temperature, the extensometer output is zeroed and the controlling variable is changed to strain.

The test is started gradually as shown in Figure 9. This procedure is used for materials that exhibit cyclic hardening in order to mimimize the excessive initial plastic strain which would result if the maximum strain were applied during the first cycle. At this time, the failsafe system is activated to prevent any additional damage to the specimen after complete fracture.

During the test, a recording of load and temperature is maintained continuously and hysteresis loops are recorded periodically. Samples of the chamber environment are taken with a hypodermic syringe and analyzed in the gas chromatograph.

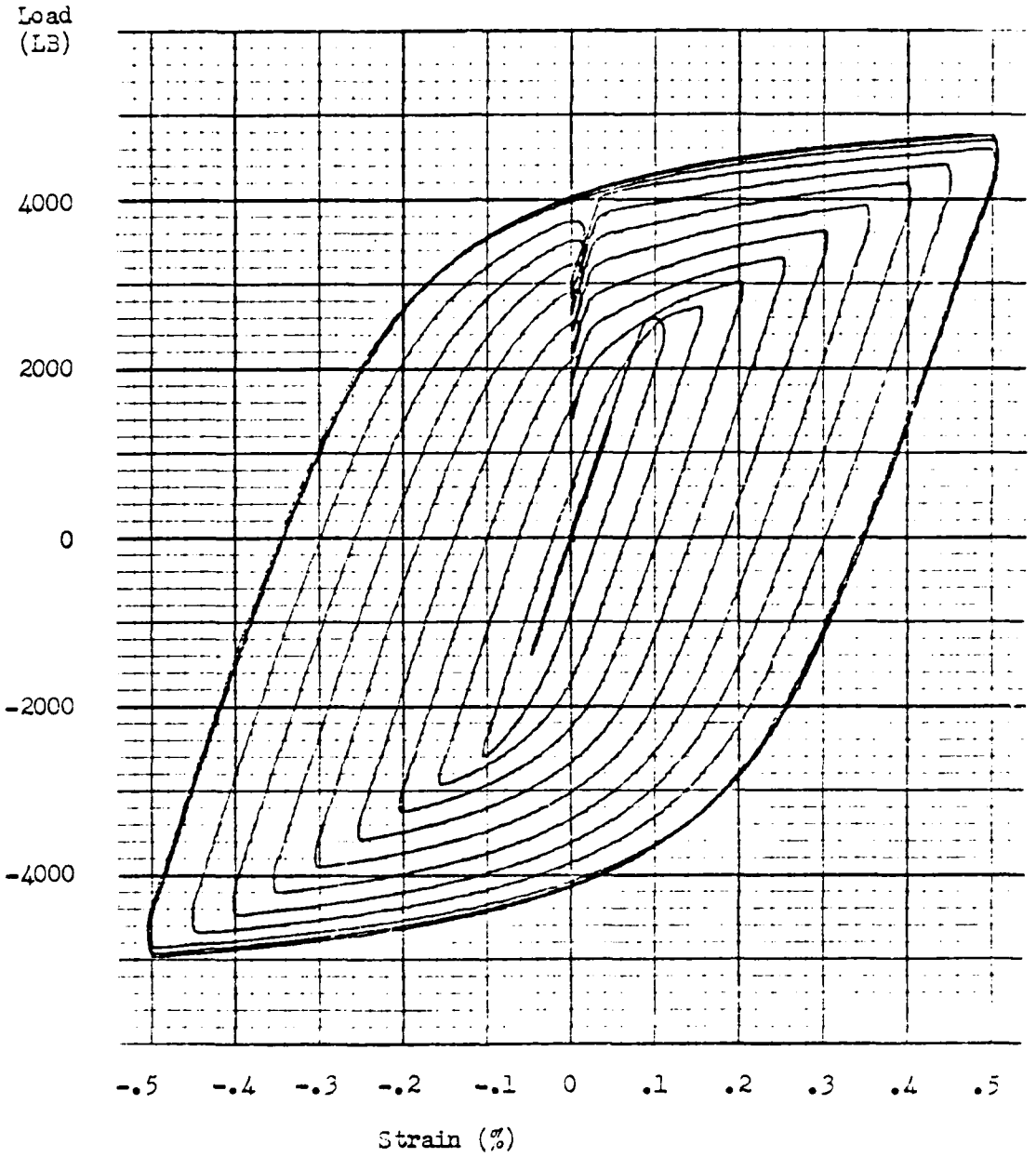

Figure 9. Hysteresis loops showing starting procedure

IV. RESULTS AND DISCUSSION

Fatigue cycling resulted in an initial rapid hardening followed by a brief (approximately 50-100 cycles) period of cyclic softening. This was followed by gradual cyclic hardening and finally a gradual softening to final fracture; as evidenced by changes in load required to maintain the prescribed total axial strain.

Results of the fatigue tests conducted are reported in Table II. The results, comparing present testings to similar testings conducted at ORNL and General Electric (G.E.), are presented in Figures 10 through 13. Both the ORNL and the G.E. tests were also conducted at a strain rate of $4 \times 10^{-3} s^{-1}$.

The following expected trends were noted:

1 - The number of cycles to failure at a given temperature de-decreased with increasing strain range.

2 - The number of cycles to failure at a given strain range decreased with increasing temperature.

The two valid tests in a helium environment were conducted at a total strain range of 1.0%. The short duration of the test and the large strain range minimizes the effects of oxidation on the crack initiation process and there is no significant difference between air and helium environments. There were two tests conducted at lower strain ranges in helium which were considered invalid. The causes which invalidated the tests were, in one case, the induction heater failed; and the other case, buckling of the specimen.

Table II

HIGH TEMPERATURE FATIGUE TEST RESULTS

Environment	Total Strain Range (%)	Temperature (C)	Cycles to Failure
Air	0.4	482	27765
Air	0.5	482	11766
Air	1.0	482	2577
Air	0.5	538	6012
Air	1.0	538	2216
He	1.0	482	2080
He	1.0	538	1927
He	0.5	482	6950[a]
He	0.5	538	7353[b]

a - Invalid due to induction heater failure.

b - Invalid due to buckling.

A comparison of the ORNL hourglass-shaped specimens and the ORNL uniform gage specimens shows an obvious trend. The ORNL uniform-gage specimens generally have a lower fatigue life than the ORNL hourglass-shaped specimens for the lower strain ranges tested and the NPS uniform-gage specimen fatigue life is lower than the other two groups.

There may be several causes for this difference. The most likely cause relates to volume of material tested by each specimen geometry. Since the uniform gage specimens have a larger volume exposed to maximum strain than the hourglass specimens, surface flaws, inclusions or other material defects which influence the fatigue crack initiation have a greater probability of being present in the gage length of a uniform gage length specimen. Likewise, the NPS uniform specimens have a larger volume and surface area exposed to maximum strain than the ORNL specimens; which accounts for an even greater reduction in fatigue life. As the number of cycles to failure increases (low strain ranges), the role of crack initiation increases. Thus, a greater effect of specimen geometry should occur at low strain ranges. This is exactly what has been observed. Since these data will be used to design large components, the fatigue life determined by the larger uniform gage specimen should be more representative of the actual service behavior of materials.

Samples of the gas from the environmental chamber were taken and analyzed in a gas chromatograph. The results appear in Table III. It should be noted that the environmental chamber and the gas chromatograph are separated by a distance of several hundred meters and the results may have a significant error due to the type syringe used to sample the environment. This is illustrated by Test 08 - 3 (Table III). In this

Table III

RESULTS OF GAS CHROMATOGRAPH TESTING

Test	Att	(cc) Vol	Type	h(ARB)	w(ARB)	A(MOD)	% O_2
06-1	200	4	He	3.0	3.5	525	1.6
07-1	100	20	He	29.0	4.2	609	1.8
07-2	1000	10	O_2	51.0	7.2	36720	
07-3	100	20	He	5.5	6.5	179	0.5
07-4	1000	20	O_2	58.0	13.0	37700	
07-5	100	15	He	5.5	3.2	117	0.4
07-6	1000	20	O_2	65.0	8.8	28600	
07-7	100	10	He	3.0	5.5	165	0.5
07-8						33150[a]	
08-1	500	8	O_2	88.0	6.5	35750	
08-2	500	8	O_2	84.0	6.3	33075	
08-3	200	8	He[b]	1.0	4.0	100	0.3
08-4	200	6	He	1.5	4.0	200	0.6
08-5	500	8	O_2	82.0	6.3	32288	
08-6	500	8	O_2	88.8	6.5	36075	
08-7	500	8	O_2	84.3	6.3	33193	
08-8	500	8	O_2	82.3	6.0	30863	
08-9	200	6	He	2.0	6.0	400	1.2
08-10						33540[c]	

a - Average value of modified area of oxygen for test 07.
b - Pure helium transported from test machine to gas chromatograph.
c - Average value of modified area of oxygen for test 08.

test, a sample was taken from a cylinder of pure helium and transported to the gas chromatograph; the oxygen content was determined to be 0.3%. The 0.3% oxygen content is alarming considering that when a helium cylinder was sampled such that the transport time to the gas chromatograph was only a few seconds, no oxygen was measured. This indicates that a substantial amount of oxygen found its way into the sampling syringe after the environmental chamber was sampled. Until an improved sampling technique is developed, the exact oxygen content of the chamber will remain unknown.

An additional test was conducted in which a sixty second hold time was introduced at maximum compressive strain. Figures 14 and 15 show creep relaxation curves taken during the testing. Although data is not available for exact comparison, the results are representative of similar testing conducted on this alloy.

The results obtained in this research validate the apparatus in that at 1.0% total strain range they are nearly identical to other tests that have been conducted by ORNL and G.E. and, at the lower total strain ranges, the differences in results can be explained by specimen geometry. The final validation of the Environmental Chamber awaits the development of an improved gas sampling technique.

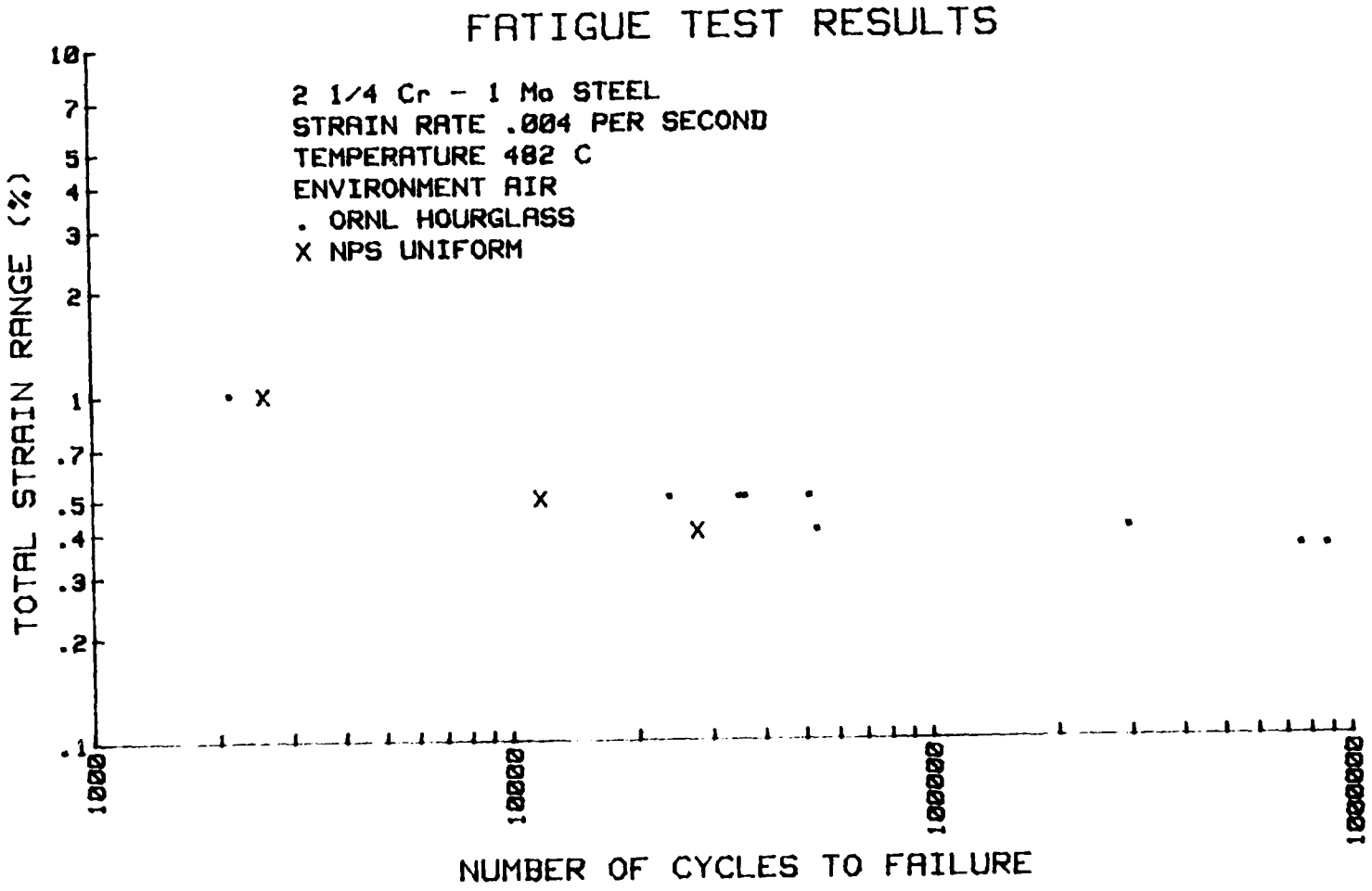

Figure 10. Comparison of Fatigue Test Results from ORNL and NPS

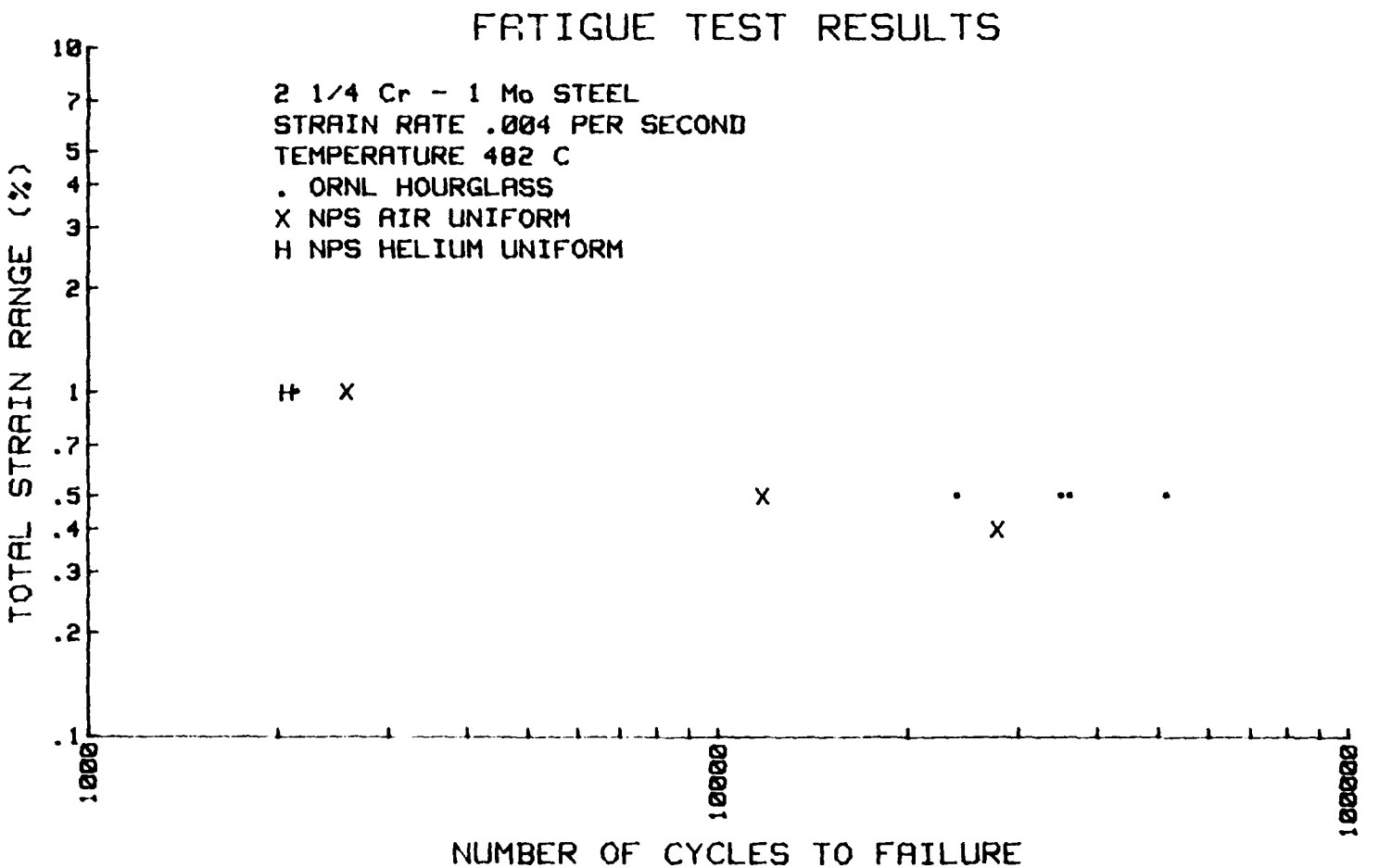

Figure 11. Comparison of Fatigue Test Results conducted in air and helium

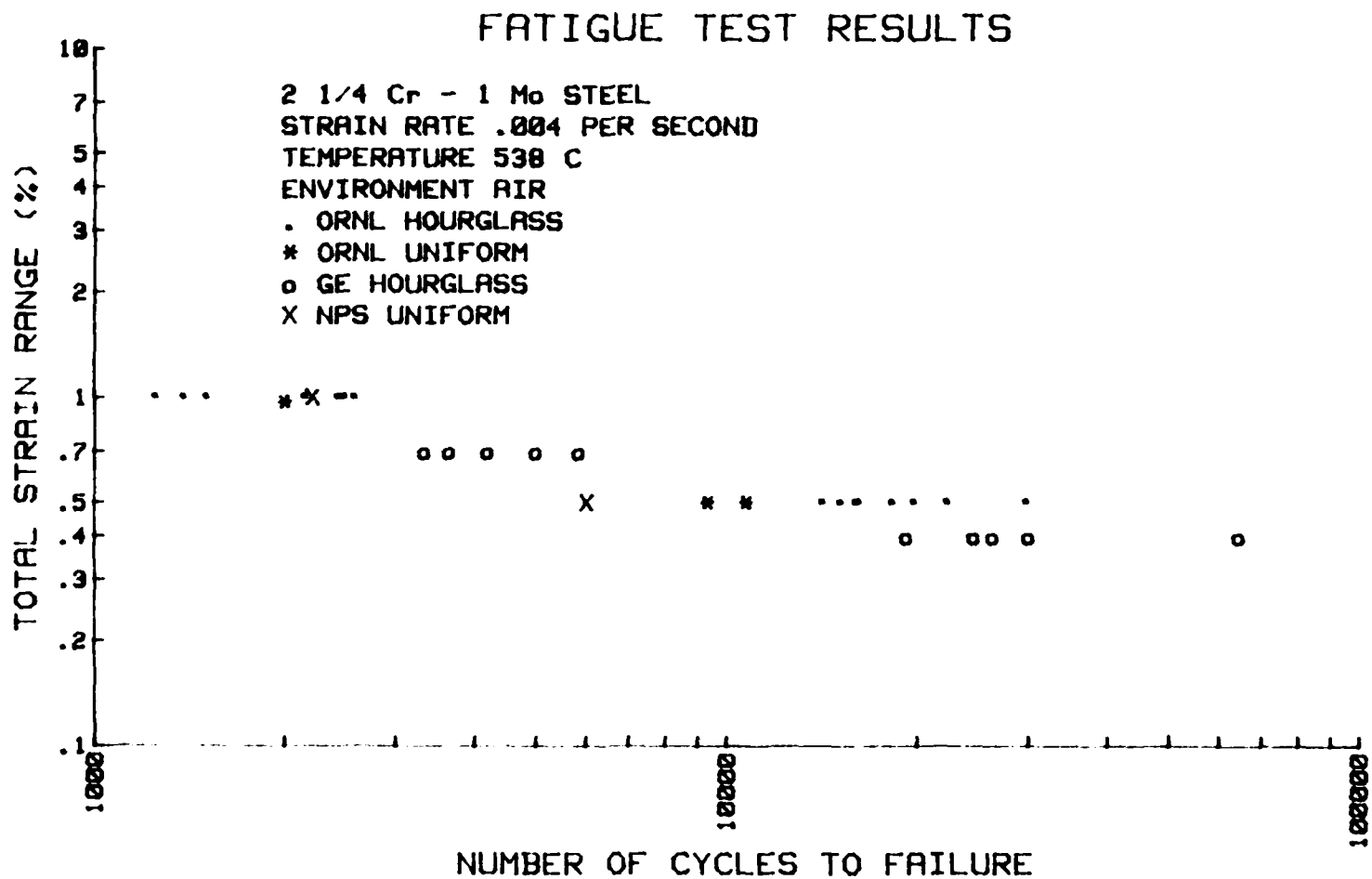

Figure 12. Comparison of Fatigue Test Results at 538 C

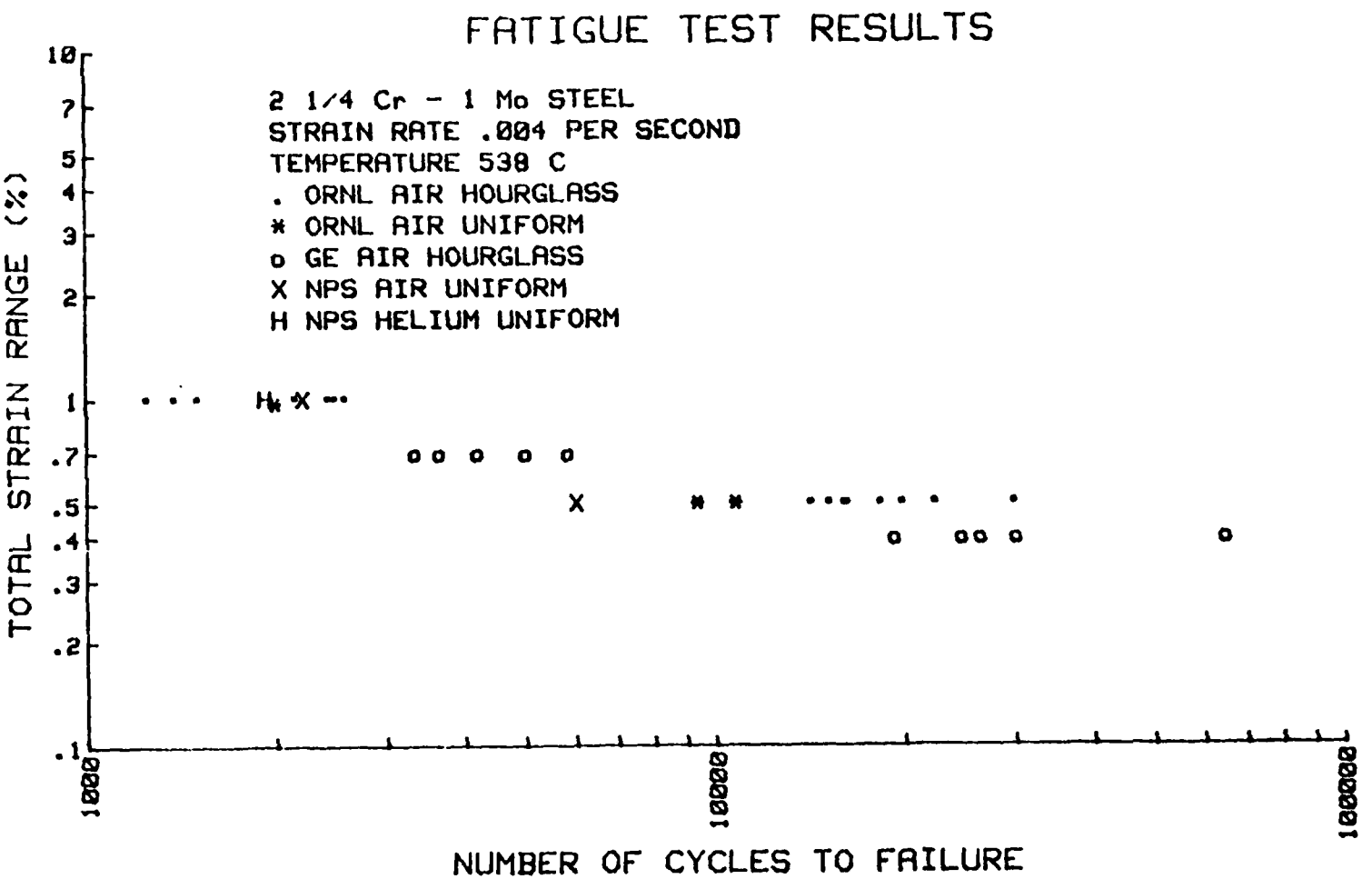

Figure 13. Comparison of Fatigue Test Results from ORNL, GE and NPS

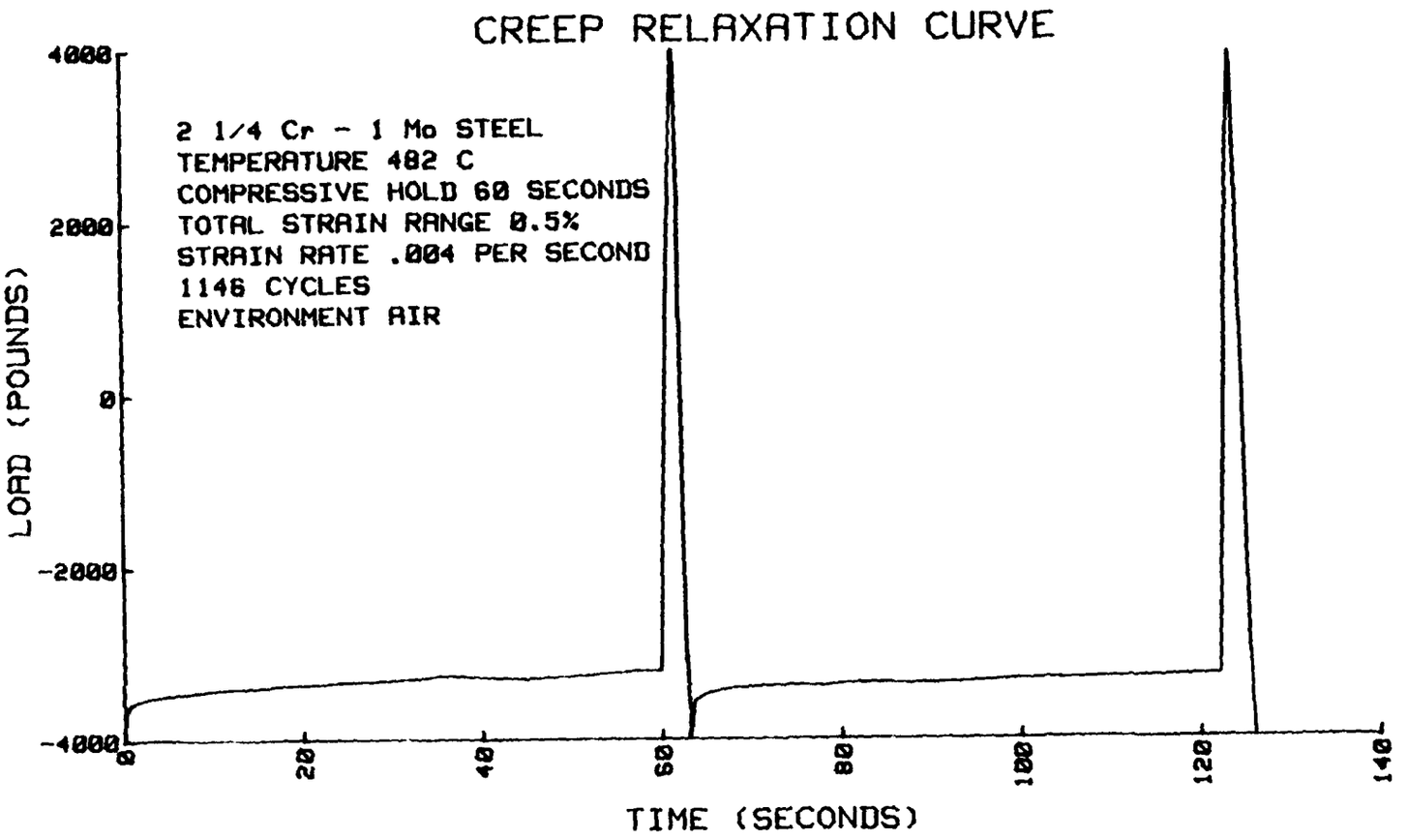

Figure 14. Two cycles of Creep Relaxation with Compressive hold 60 seconds

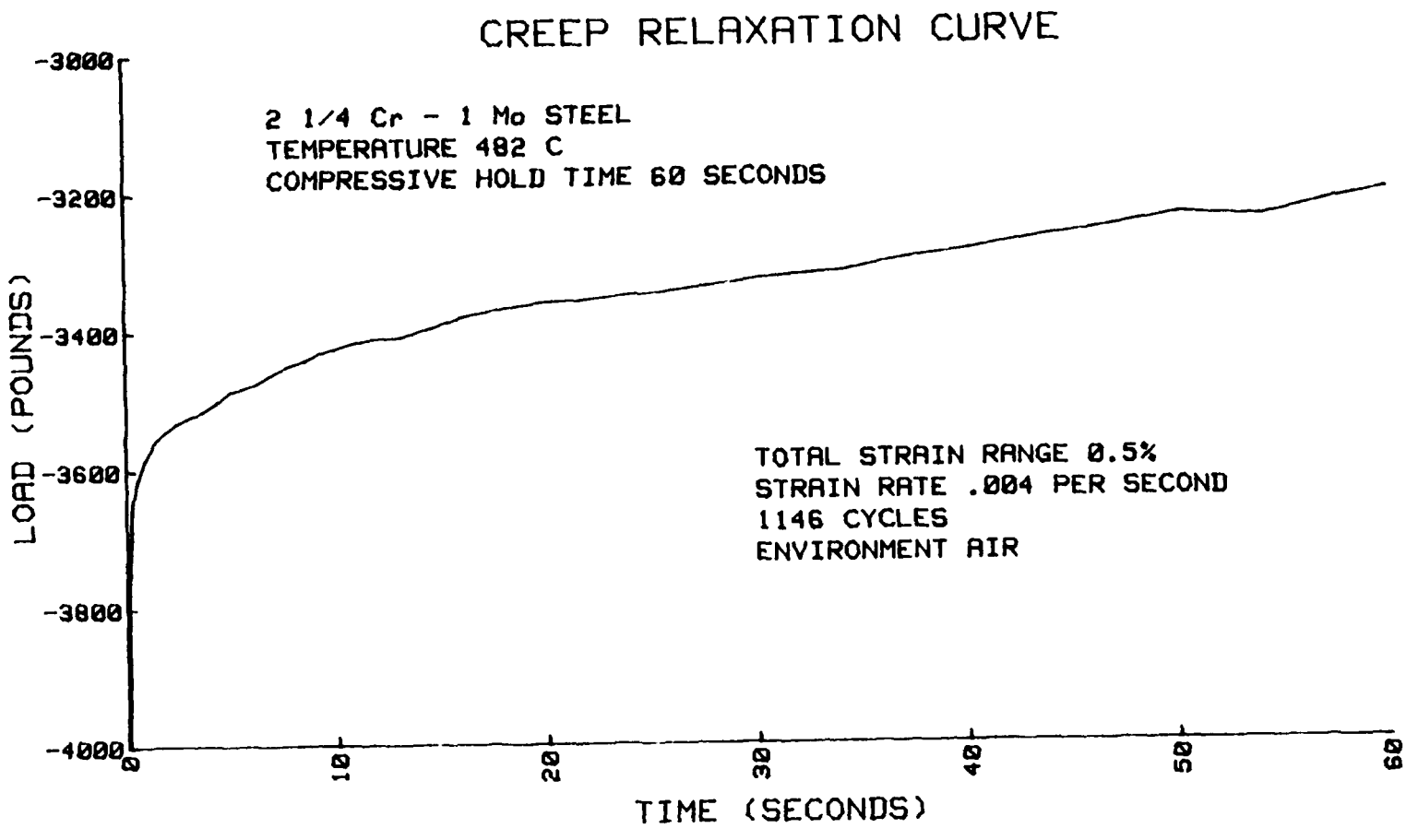

Figure 15. 60 second Creep Relaxation Curve

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The basic conclusion is that the apparatus designed is valid for performing high temperature fatigue tests in an inert environment.

2. The test results performed with the specimen geometry in Figure 8, give conservative results. This is significant in that the results will be used to establish design information.

B. RECOMMENDATIONS

1. Research should be continued with the design apparatus to separate the effects of creep and environment on elevated temperature fatigue.

2. Bellows for the load cell and actuator extensions and an industrial seal for the door should be installed to lower the oxygen in the Environmental Chamber.

3. Improved gas sampling techniques must be developed in order to accurately measure the oxygen content of the test environment.

APPENDIX A

Checklist and example settings

The purpose of this appendix is to provide a detailed checklist for performing the elevated temperature fatigue tests. The parameters in the example used consist of the following:

1. The strain rate is 4×10^{-3} s^{-1}.
2. The total strain range is 1.0%.
3. A fully-reversed fatigue test is to be conducted having a triangular wave form without hold time.
4. The gage length is one inch and specimen as in Figure 3.

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
. . . . .	CONSOLE TURN ON	. . . . .
__1.	Turn CONSOLE POWER on.	413.05 OP, page 2
. . . . .	PRELIMINARY ADJUSTMENT	. . . . .
__2.	If the load cell, Extensometer clip-on gage, or LVDT is changed, ensure that the proper arange card is installed in the appropriate transducer conditioner. NOTE: G32.51B Extensometer	440.21 OP, page 6 440.22 OP, page 6
. . . . .	PROGRAMMING	. . . . .

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
__3. Select desired controlled variable. Control panel interlock must be open (RESET lit).	x LOAD ___ STRAIN ___ STROKE	440.31 OP, page 2
__4. Select desired operating range.	LOAD ±% FS Full Scale = ± 20KIP RANGE x 100 1 ___ 50 2 ___ 20 3 ___ 10 4	440.21 OP, page 3
	STRAIN ± F.S. RANGE ___ 100 1 ___ 50 2 ___ 20 3 x 10 4	440.21 OP, page 3
	STROKE ± FS Full Scale = ± 7 in. RANGE x 100 1 ___ 50 2 ___ 20 3 ___ 10 4	440.22 OP, page 3
__5.1 Adjust Digital Function Generator	CONTROL MODE x REMOTE ___ LOCAL ___ SINGLE CYCLE OUTPUT x RAMP ___ SINE ___ HAVERSINE ___ HAVERSQUARE ___ INVERT BREAKPOINT ___ NORMAL ___ REVERSE	410.31 OP

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
	LOCAL	
	___ NORMAL _x_ REVERSE	
	1000 PERCENT	
	___ DUAL SLOPE ___ HOLD AT BRKPT _x_ RAMP THRU ZERO ___ MANUAL BRDPT (OVERRIDE)	
	$\frac{1.3 \times 10^{0}}{\text{RATE 1}}$	
	X 10 RATE 2	
___5.2 Check correct function with oscilloscope		
___6. Adjust Counter Panel	COUNTER INPUT	417.01 OP
	___ DATA-TRAK _x_ OSCILLATOR (410.31) ___ AUXILLARY	
	COUNT MULTIPLIER:	
	_x_ X1 ___ X10 ___ X100	
	999999 PRESET COUNT	
	000000 COUNTER	

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
__7. Calculate and record SET POINT	498 SET POINT	440.13 OP, pages 3-7
__8. Adjust SPAN 1 for desired Digital Function	250 SPAN 1	440.13 OP, pages 3-7
. . . . . READOUT ADJUSTMENTS		
__9. Adjust Recorder Input Selector, if applicable	X: Output switch ___ CAL ___ LOAD _x_ STRAIN ___ STROKE ___ PROG 1 Inner Switch _x_ (+) ___ (-) ___ OFF Y_1: Outer Switch ___ CAL _x_ LOAD ___ STRAIN ___ STROKE ___ PROG 1 Inner Switch _x_ (+) ___ (-) ___ OFF	442.11 OP
__10. Adjust Recorder, if applicable.		XY Recorder Manual in Reference Manual

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
__11. Adjust oscilloscope Input Selector, if applicable	X: Outer Switch ___ CAL ___ LOAD _x_ STRAIN ___ STROKE ___ PROG 1 ___ SYNC Inner Switch _x_ (+) ___ (-) ___ OFF Y_1: Outer Switch ___ CAL _x_ LOAD ___ STRAIN ___ STROKE ___ PROG 1 Inner Switch ___ PEAK _x_ (+) ___ (-) ___ OFF	442.11 OP
__12. Adjust Oscilloscope, if applicable.		Oscilloscope manual in Reference manual
. . . . . FAILSAFE ADJUSTMENTS		
__13. Adjust Error Detector	ED2___%	440.13 OP, pages 8-10

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
__14. Adjust Error Detector 1 for Null Detection in desired.	___%	440.13 OP, page 11
__15. Adjust Limit Detectors, if applicable.	XDCR 1 (LOAD)	440.41 OP, page 4
	1000 UPPER	
NOTE: This step may be performed after test has started. See 440.41 OP, page 5	_x_ (+) ___ (-)	
	1000 LOWER	
	___ (+) _x_ (-)	
	_x_ INTERLOCK ___ INDICATE	
	XDCR 2 (STRAIN)	440.41 OP page 4
	500 UPPER	
	_x_ (+) ___ (-)	
	500 LOWER	
	___ (+) _x_ (-)	
	___ INTERLOCK _x_ INDICATE	

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
__15. (Continued)	XDCR 3 (STROKE) 1000 UPPER __x__ (+) _____ (-) 300 LOWER __x__ (+) _____ (-) __x__ INTERLOCK _____ INDICATE	440.41 OP page 4
__16. If desired, adjust Under Peak detection if applicable. Notes: a. This step may be performed after test run has started. See 440.51 OP, page 10. b. Amplitude Measurement feature can not be used if Under Peak detection is used. c. If amplitude measurement is desired proceed to next heading.	OSCILLOSCOPE Y_1 (Outer) _____ CAL __x__ LOAD _____ STRAIN _____ STROKE _____ PROG 1 MAX reference control __x__ PEAK 065 MAX __x__ (+) _____ (-) 000 MIN _____ (+) __x__ (-)	440.51 OP page 9

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
	FAILSAFE ___ ACTIVE _x_ OUT	
. . . . . PRELIMINARY ADJUSTMENTS AND HYDRAULIC TURN ON		
__17. Monitor DC ERROR on the Controller meter		440.13 OP page 8
__18. Null the meter using the SET POINT control		440.13 OP page 3
__19. Push RESET on the control panel if it is lit.		413.05 OP page 2
NOTE: If at any time RESET will not extinguish, look for an abnormal condition as described on the last page of this Checklist under IN CASE OF SYSTEM SHUTDOWN.		
__20. Set AUTO RESET switch to OUT.		440.14/.14A OP, page 2
__21. Turn HYDRAULIC PUMP on.		
__22. Push HYDRAULIC PRESSURE on the control panel (LOW pressure condition).		413.05 OP, page 6
If at any time an emergency occurs, push EMERGENCY STOP-HYD. OFF		
__23. Lower Hydraulic Actuator to bottom stop	SET POINT 550	
. . . . . INSTALLING THE SPECIMEN		

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE

__24. Select HIGH pressure. Raise Crosshead to a position grip two inches from top of Environmental Chamber.

__25. Select LOW pressure. Mount specimen with the thermocouples in rear. Tighten Locking collar with spanner wrench. Plug thermocouples into receptacles.

__26. Set TEMPERATURE CONTROL to ON and adjust SETTING. Pyrometer ON. Check Temperature readout.

__27. Center Locking Collar into bottom grip.

__28. Select HIGH pressure. Lower Crosshead to yellow marking on FRAME.

__29. Select LOW pressure. Insert Split Specimen Retainers.

__30. Raise Actuator slowly using SET POINT control, simultaneously thread Locking Collar into bottom grip. Tighten Locking Collar using spanner wrench. Insure thermocouple wire is not touching induction coil.

__31. Check LOAD is zeroed. Adjust if necessary.

__32. Apply tensile load to specimen. Apply HYDRAULIC pre-load. SET POINT 550

CHECK PROCEDURE		RECORD ADJUSTMENT	MANUAL REFERENCE
__33.	Adjust Oscilloscope Input Selector	Y_1:	
		OUTER SWITCH ___ CAL _x_ LOAD ___ STRAIN ___ STROKE ___ PROG 1	
__34.	Select HIGH pressure. Adjust LOAD to zero	SET POINT 498	
. . . . . MOUNTING EXTENSOMETER			
__35.	Rotate Extensometer Mount into position. Line-up Fixed Radiation Shield with marking on Extension Rod. Tighten into position.		p. 4-3 LHAC Ref. Man.
__36.	Separate Extension Rod to one inch.		
__37.	Adjust Oscilloscope Input Selector	Y_1:	
		OUTER SWITCH ___ CAL ___ LOAD _x_ STRAIN ___ STROKE ___ PROG 1	
__38.	Adjust STRAIN voltage to zero.		
__39.	Switch XDCR 2 Limit Detector to INTERLOCK.		
. . . . . INERT ENVIRONMENT ONLY			

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
__40. Insure seals and sealant are tight.		
__41. Close Environmental Chamber door.		
__42. Close Manometer Input Valve. Connect Vacuum Pump hose. Open valve for Vacuum pump. Insert Vacuum pump plug. Wait ten (10) seconds.		
__43. Adjust regulator to 25 PSI. Open output valve from regulator. Slowly open MANOMETER INPUT valve. Flush system with 40 cubic feet of Helium.		
__44. Adjust regulator pressure to 10 PSI. Adjust chamber pressure.		
. . . . . INDUCTION HEATER		
__45. Turn water pump ON		p. 10 Cycle Dyne IHAO
__46. TIMER - OFF. OVERLOAD SWITCH UP position. LINE CIRCUIT BREAKER ON.		p. 10 Cycle Dyne IHAO
__47. Push START button. Monitor Temperature.		
__48. Adjust STRAIN voltage to zero.		
__49. Switch to STRAIN CONTROL		
. . . . . STARTING TEST RUN		

CHECK PROCEDURE	RECORD ADJUSTMENT	MANUAL REFERENCE
__50. To start test, push PROGRAM & RECORD on the Control Panel. RUN will light and programmer will start.		
__51. Adjust Controller GAIN	4.8 GAIN	
__52. Adjust Amplitude Measurement Panel.	FAILSAFE _x_ ACTIVE ___ OUT	

APPENDIX B

Gas Chromatograph Calculations

The purpose of this appendix is to briefly describe the operation and interpretation of output of the Bendix ChronoLab 2200 Gas Chromatograph (GC).

Switches 1 through 4 should be turned on two hours before intended use. Switch 5 and the chart recorder should be turned on just prior to operation. Attenuation should be set at 100 for a sample from the Environmental Chamber and 1000 for a sample of pure oxygen (located to the right side of GC). The samples are injected in port 1.

The following example is based on Figures A1 and A2. All units are dimensionless.

TERMS:

L = Amplitude of peak

$w(\frac{1}{2}h)$ = Width at one-half of peak amplitude

Att = Attenuation

Vol = Volume

A = Modified area

BASIC EQUATION

$$A(x) = h \times w \times Att \div Vol$$

From Figure B1 the oxygen standard data is:

h = 51

w(25.5) = 7

Vol = 10

Att = 1000

A (oxygen standard) = 51 x 7 x 1000 ÷ 10 = 35700

From Figure B2 the impure helium sample data is:

h = 29

w(14.5) = 4

Vol = 20

Att = 100

A (sample) = 29 x 4 100 - 20 = 580

Calculation of the percent oxygen:

$$\% O_2 = \frac{A \text{ (sample) x } 100}{A \text{ (oxygen statndard)}}$$

$$= \frac{580}{35700}$$

$$= 1.6\% O_2$$

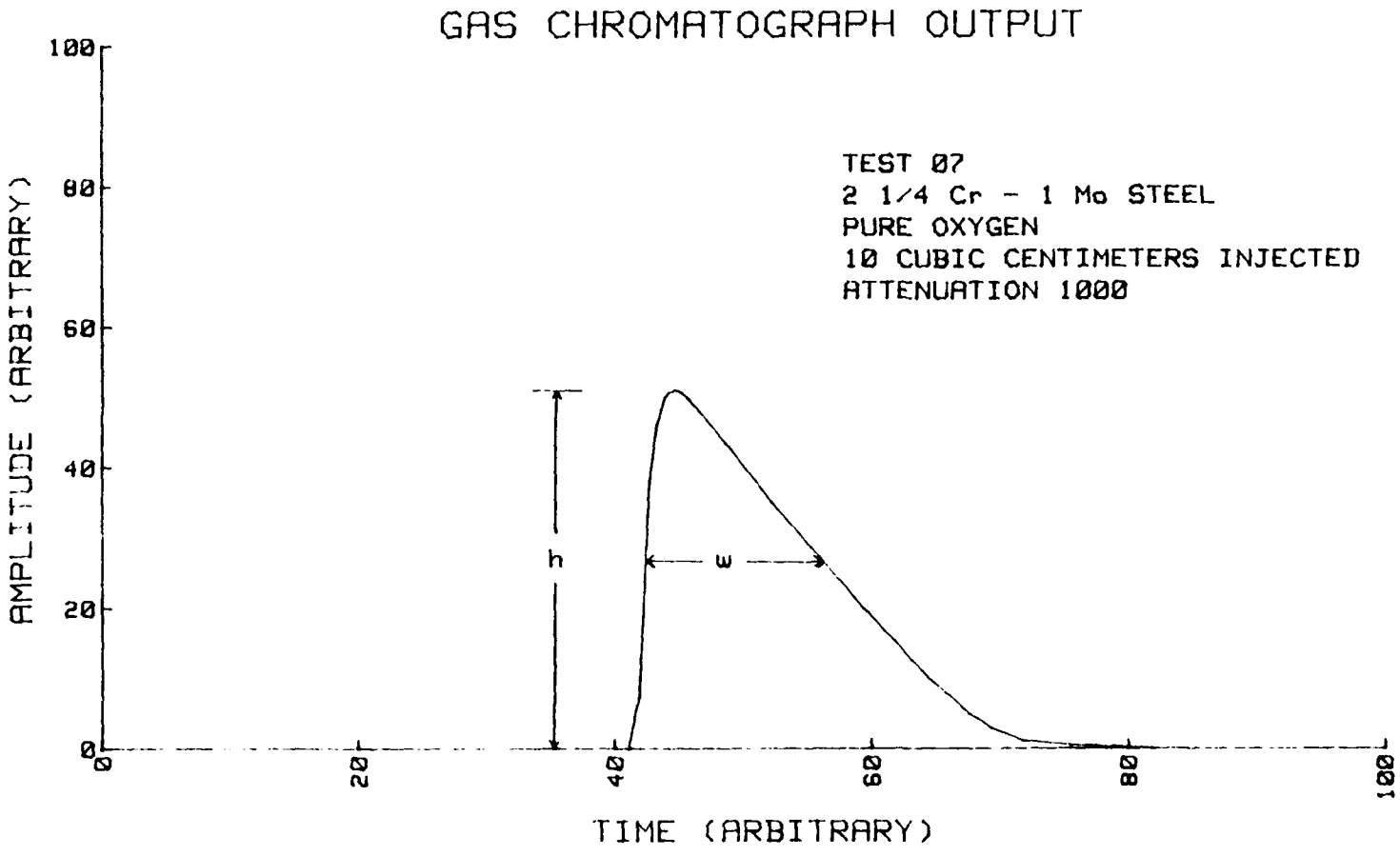

Figure B1. Pure oxygen standard Gas Chromatograph Test

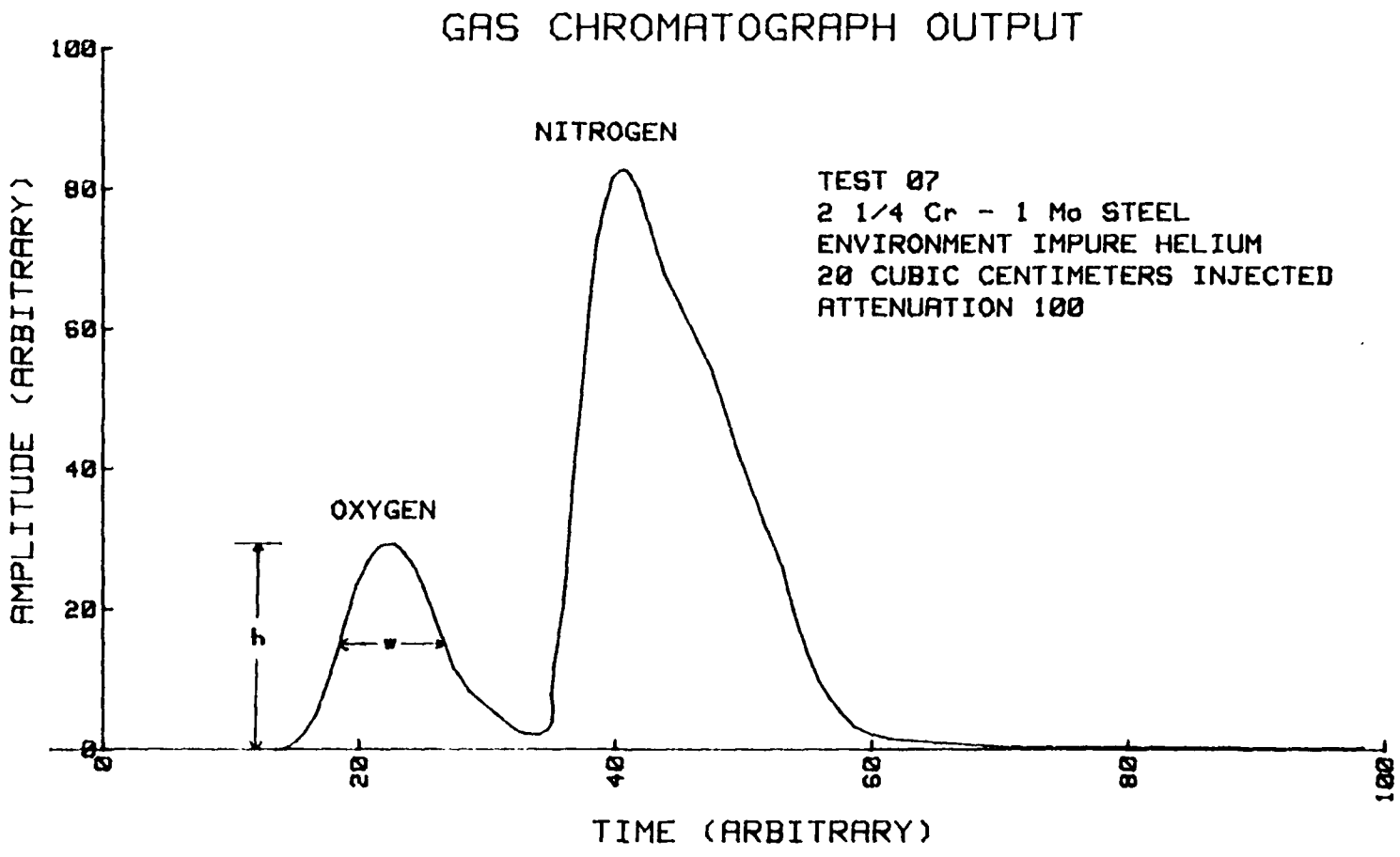

Figure B2. Gas Chromatograph Output of sample taken from Environmental Chamber

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